APPENDIX B

REASONABLE WORST CASE ANALYSIS
INJURY TO FINFISH

REASONABLE WORST CASE (RWC) ANALYSIS
FINFISH RESOURCES

1.0 INTRODUCTION

This analysis evaluates the direct finfish (fish) service losses associated with aquatic habitats in Lavaca Bay, which may be a result of releases of hazardous substances from the Site. The main habitats considered in this process are marsh/mudflat, oyster reefs and open waters. The food web associated with fish generally connects herbivorous, omnivorous and planktivorous fish with carnivores and scavengers. The food web may be water column based, with plankton as the base of the web, or sediment based, with benthic organisms as the base. Some of the types of services that are provided by finfish resources that can be affected by contaminants include:

- **Food and Productivity:** The finfish community includes numerous lower trophic level organisms that are highly productive and serve as food sources for higher trophic level organisms. Herbivorous fish feed on phytoplankton, algae or other plant material. Omnivorous fish of various types use water column and sediment based food webs. Several levels of carnivorous fish are present in Lavaca Bay habitats.
- **Energy Cycling:** Finfish are critical components of the estuarine food web and are essential for the energy cycle of the estuarine system.
- **Recreational Use:** Finfish offer various recreational uses for humans. Many species are subject to recreational fishing and are managed to provide this service.

Finfish resources provide critical ecological services, which affect all organisms within the aquatic ecosystem of Lavaca Bay. Injuries to these resources have the potential to adversely impact biota in nearly all trophic levels of the area ecosystem.

Lavaca Bay provides significant diversity and abundance of finfish populations throughout the year. In an estuarine system, these populations are a very important functional group in ecological food webs. The primary ecological services provided by finfish include food, consumption and production, and energy cycling. The recreational use of fish in Lavaca Bay is an important service provided to humans. There has been a fishing closure present for a portion of Lavaca Bay since 1988. The effect of the closure on the recreational fishing services is being assessed separately since the methodologies used to assess human use of finfish differ substantially from those used to evaluate ecological service losses.

In Lavaca Bay, injury to finfish populations due to the Site can occur as a result of two types of events:

1. Direct exposure to mercury in sediments and surface water or through ingestion of contaminated prey as a result of bioaccumulation or biomagnification of mercury or methyl mercury in aquatic food webs; and
2. The elimination of habitat used by fish through physical removal or dredging. The latter loss can occur as a result of remedial actions taken to reduce unacceptable risk to human health or the environment. Service losses for finfish populations that occur as a result of habitat destruction or elimination through remedial activities will be evaluated at the habitat level. That is, the area, or quantity, of habitat impacted can be measured directly for restoration

planning, and any associated service losses at the resource level (e.g., for benthos or finfish and shellfish) will also be addressed via the services provided by the restored habitat(s).

The injury assessment and quantification of habitat losses associated with remedial activities will be described in a separate technical memorandum. In assessing the ecological service injuries for Lavaca Bay, the interrelated aspects of the various components of the ecosystem must be considered to avoid double counting injuries common among the resources. To address this issue, the Trustees are evaluating most injuries through the assessment of benthos (see the RWC Analysis Injury To Benthos technical memorandum). The RWC Analysis Injury To Finfish technical memorandum will address only those injuries to fish potentially resulting from the bioaccumulation of mercury, such as behavioral alteration, survival, growth, and reproduction.

2.0 EVALUATION OF INJURY

Finfish are exposed to risk of injury from mercury through several pathways including ingestion of sediments, food ingestion, dermal contact, and exchange across gill membranes. To develop an understanding of the risk of injury through the most likely exposure pathways, representative species (receptors) were selected for evaluation. This was necessary since not all species, or the complete food web, of the bay could be assessed in a scientifically reasonable, or cost effective, manner. The evaluation was undertaken in a parallel process with the ecological risk assessment being undertaken as part of the Remedial Investigation for the NPL Site, so complimentary data needs could be satisfied without duplicating efforts. Representative species were selected for the major feeding guilds that commonly use the habitats within Lavaca Bay. The selection of the representative species is described in the Baseline Risk Assessment Report (Alcoa, draft BLRA). Representative species were selected that demonstrated exposure pathways presenting the greatest exposure of organisms to the contaminants of concern. Also, the representative species selected were locally abundant and known to be sensitive to contaminant effects, such as mercury. Using these sensitive, representative species, it was possible to develop a RWC estimation of injury to the fish community of Lavaca Bay.

The use of representative species to determine ecological impacts to biological communities is a common practice in environmental impact assessments. Representative species selection criteria are designed to designate species that are important to the area ecosystem and sensitive to the environmental impact being assessed. For assessments addressing Clean Water Act requirements, representative species are often referred to as "resident important species" or "representative important species." In ecological risk assessment procedures such species are often referred to as "representative species" or "surrogate species." The general process follows the belief that if the effects on (or protection of) important, sensitive species are determined, effects on (or protection of) other less important, less sensitive organisms in the ecosystem are also encompassed. Following the criteria discussed above, the representative species for this injury assessment were selected because: 1) they are similar to organisms used in toxicity research noted in the literature, 2) site specific data exists from Lavaca Bay on these species, 3) the species are significant to the Lavaca Bay ecosystem, and 4) the species' life history stages and interactions with habitats of concern occur in Lavaca Bay.

The assessment process used information from the Remedial Investigation of the NPL Site, other studies of Lavaca Bay, and other supporting literature, including the following information:

- Analytical data collected in the Remedial Investigation documenting the nature and extent of contamination in aquatic habitats (Alcoa, draft Remedial Investigation Report),

- Habitat mapping data developed for Lavaca Bay in the Remedial Investigation (Alcoa 1997),
- Data available on contaminant levels in fish and prey item tissues (Alcoa 1998),
- Information from the NPL Site ecological risk assessment for aquatic ecosystems (Alcoa, draft Baseline Risk Assessment Report), and
- Information from the literature on adverse effects of contaminants on the behavior, growth, survival and reproduction of fish.

In the baseline ecological risk assessment for the NPL Site, it was determined that only PAHs and mercury may pose an important risk to ecological receptors in the bay (Alcoa, draft BLRA). Based on the risk assessment results and because PAHs are metabolized and eliminated quickly by fish (which limits their toxic effects), the Trustees determined that only mercury was found at concentrations warranting further assessment for injuries to finfish resources. A literature review provided several recent published, or referenced, study results indicating that tissue concentrations of mercury might be used to determine injury levels for fish. Because of the large database on fish tissue concentrations in the bay, including historical data to 1977, the Trustees decided to use critical tissue concentrations to assess injuries to finfish.

2.1 Critical Tissue Concentrations for Mercury in Finfish

2.1.1 Issues with Critical Tissue Concentration Assessments

The use of critical tissue concentrations in assessing adverse effects and ecological risks to fish is a fairly new area of scientific study. There is not an extensive amount of information available on critical tissue levels determined in experiments that have assessed a complete range of concentrations from no effect to lethal levels. The general lack of comprehensive data on no effect and effect concentrations, and the limited number of species with data on effect levels in critical tissues, often results in some uncertainty concerning the accuracy, and repeatability, of conclusions drawn using critical tissue evaluations.

In recent years, the amount of information concerning potential risk posed by mercury to fish based on concentrations present in tissues has increased. This is particularly true with regard to behavioral and reproductive effects not normally assessed through laboratory toxicological bioassay experiments. A number of studies have related adverse effects to mercury body burdens for several different species of fish. To account for the uncertainty and to ensure the public is compensated for the finfish injuries in Lavaca Bay, the Trustees have been conservative in assessing the effects of mercury on fish in this Reasonable Worst Case evaluation using critical tissue concentrations.

2.1.2 Literature Review of Mercury Critical Tissue Concentrations

A range of biological effects related to mercury concentrations in fish tissue is noted in the literature for finfish species with wet weight tissue concentrations ranging from 0.25 to 20 μg/g (Table 1). While behavioral effects have been noted at body burdens of less than 1 μg/g, there is uncertainty inherent in attempting to interpret these body burdens for fish from Lavaca Bay to body burdens in unrelated test species under controlled laboratory conditions. The uncertainty is greatest with the lowest effect levels reported in the literature. However, the Trustees have determined that sufficient information is available to make a sound injury determination for Lavaca Bay resources. Literature reviews of mercury studies provide general assessments of effect levels (Niimi and Kissoon 1994; Wiener and Spry 1996; Beckvar et al. 1996). By assessing these literature reviews and more recent studies on effects and tissue concentrations, it is possible to develop consistent general injury determinations for mercury in fish tissues. This section describes the Trustees' evaluation of the literature to determine injuries to finfish of Lavaca Bay. Since most mercury data for Lavaca Bay fish exists as muscle tissue (with some whole body data) concentrations, this assessment stresses literature studies reporting muscle and whole body tissue concentrations for injury determinations.

Table 1 lists the results of selected studies and literature reviews being used in this injury assessment. This document discusses this information and other information supporting the injury assessment. Niimi and Kissoon (1994) conducted a literature review that indicated whole body concentrations of 10 – 30 mg/kg were lethal for fish. The authors interpreted the literature as indicating that mercury concentrations of 1 – 5 mg/kg in tissues of aquatic organisms were indicative of adverse chronic effects. They based their conclusions on studies such as those conducted by McKim et al. (1976) that indicate a concentration of 3 mg/kg in muscle as the maximum allowable toxicant concentration in brook trout before effects were noted. Olson et al. (1975) found no observable effects for adult fathead minnows at 1.4 – 10.9 mg/kg in whole fish, but Snarski and Olson (1982) found 1.4 mg/kg in whole fish was the maximum allowable toxicant concentration in fathead minnows when considering reproductive impairment and impaired larval growth. This illustrates that reproduction, early life stages and behavioral impacts are the most sensitive end points for assessing mercury impacts to fish. Reviews noted that different injury levels would be determined depending on whether adult, reproductive/early life stage or behavioral effects were assessed.

Most mercury in fish tissues is present as methyl mercury, with the percentage of methyl mercury increasing the higher the organism is in the foodweb or trophic structure. Wiener and Spry (1996) noted that the foodweb, or trophic structure of a system, influences the level of mercury accumulated by top predators. However, it was also noted that it does not matter where the methyl mercury found in fish tissues came from since it is distributed and reacts in the same manner once it is in the fish. This means data from studies on accumulation of waterborne methyl mercury in tissues are still valid to develop conclusions for critical tissue concentrations, even though concentrations in wild fish are obtained mostly through their diet. They postulated that mercury concentrations above 6 – 20 μg/g result in adverse toxic effects in adult salmonids. Wiener and Spry (1996) also discussed that behavioral studies might show effects at tissue concentrations much lower than indicated for other effect endpoints due to the neurotoxicity of mercury. They noted that early life stages are very sensitive to mercury and that environmental exposure, or maternal transfer into eggs, could result in injury. They discussed how fish embryo survival could be substantially reduced with 1-10% of the tissue residues in adult fish muscle present in the fertilized eggs or larvae. Therefore, the most sensitive endpoints for injury assessment would be larval fish, especially for behavioral impairment. The receptors most at risk for these effects would be non-migratory species that spend all, or most, of their life cycle within the area with elevated mercury concentrations in the sediments. Migratory species, especially those that migrate to spawn, would be at less risk since they continue to depurate mercury after they leave the area with elevated mercury and so do not maintain the elevated mercury levels in their systems.

Beckvar et al. (1996) noted the same tissue concentrations of concern listed in Niimi and Kissoon (1994) and Wiener and Spry (1996), but noted concern for reproductive or early life stage effects at mercury concentrations of 0.5 – 1.0 ppm in fish whole bodies. Friedmann et al. (1996) found low levels of dietary methyl mercury inhibited growth and gonadal development in walleye. Juvenile fish fed fillets dosed with methyl mercury (Hg) at two levels (0.1 and 1.0 g Hg/g food) developed body burdens of mercury of 0.254 (± 0.015) μg Hg/g and 2.37 (± 0.09) μg Hg/g, respectively. The fish exhibited impaired growth and gonadal development in males.

Testicular atrophy was observed and suppressed plasma cortisol was noted in juveniles (sexes combined). The results suggest juvenile survival might be reduced due to impaired growth and immune function. Reproductive potential might also be adversely affected due to impaired testicular development in juveniles. Other studies have noted that early life history behavioral impairments in this range of body burdens could result in reduced recruitment in species that reside in areas with elevated mercury for most of their life history. Matta et al. (1999) and Matta (In review) noted higher mortality in male mummichog at body burdens of 0.47 – 11.0 µg/g. While Vollestad et al. (1998) found only a slight departure from morphological norm for grayling fry with 0.27 – 3.80 µg/g mercury in whole body samples as fry, Fjeld et al. (1998) noted impaired feeding efficiency and reduced competitive ability for this same group of experimental fish as subadults. The Friedmann et al. (1996) and Fjeld et al. (1998) papers may indicate long-term effects in fish, with low body burdens of mercury, exposed at critical life stages, i.e., juvenile testicular development and fry feeding ability. This may indicate that though non-migratory species have the greatest overall exposure, migratory species may have risk if exposure occurs at critical life stages (e.g., larval and early juvenile exposure).

In a series of papers, Weis, Weis and Zhou found that mummichog (Fundulus heteroclitus) exposed to low levels of methyl mercury in water developed behavioral impairments that lowered prey-capture ability while exposing themselves to greater predation pressure. These impairments would disappear if the exposure to mercury was removed. Weis and Weis (1995) found that larvae exposed to 5 µg/L methyl mercury in water exhibited slower prey-capture ability that recovered in about one week after the exposure was removed. Zhou and Weis (1998) noted that embryonic or larval exposure resulted in behavioral impairment and increased vulnerability to predation by yearling mummichogs. Zhou et al. (1998) indicated that tissue concentrations from exposures to the levels of mercury inducing these effects varied with exposure concentration and exposure time. Larval body burdens of mercury ranged from about 0.4 – 1.5 µg/g for the lowest contaminant exposure concentrations found to result in behavioral impairment in the other studies.

From the literature, it appears that adverse behavioral and reproductive effects commonly appear with tissue concentrations of approximately 0.5 µg/g in fish muscle tissue or whole body samples. These effects normally occur in larval to subadult life stages. Often the effects are transitory and are eliminated if the organisms are removed from the area of elevated mercury, but sometimes exposure at critical life stages may result in long-term impairment. This indicates that injury occurs at these tissue concentrations for resident, non-migratory species. In estuarine systems, these non-migratory species are plentiful (such as killifish, sheepshead minnows, blennies, and gobies) and often comprise a majority of the prey items for large, piscivorous predators. Injuries increase with increasing tissue concentrations. Toxic effects become apparent for migratory and non-migratory species when muscle tissue concentrations are approximately 2.0 µg/g. At this degree of injury, most fish species are at risk including red drum, black drum and flounder. The severity of the effects increases with higher tissue concentrations with lethal toxic effects occurring for most species between 6 and 20 µg/g. Table 2 lists the critical tissue concentrations with the injuries associated at those concentrations.

2.2 Relating Critical Tissue Concentrations to Sediment Concentrations

In using critical tissue concentrations to identify injury to Lavaca Bay receptors, the relationship with the concentrations existing in site media must be determined in order to establish where the areas that may cause injury are located within the bay. As noted in Wiener and Spry (1996), the source of the mercury to the fish does not matter in determining critical tissue levels since mercury is processed in the same manner no matter how it enters the body. However, to determine the origins of the injury, we need to assess the inputs (sources) of mercury to the receptors. There are essentially two major uptake routes available for fish: intake across the gills and through consumption via the digestive system. The major components of these routes are from the water column (gill uptake) and from the sediments ("dirty food" ingestion). The "dirty food" ingestion can include the direct ingestion of water and sediments as well as consuming contaminated food items.

The importance of water column or sediment based mercury can vary with the organism, its life stage, diet and seasonal factors (Post et al. 1996). However, studies in Lavaca Bay have indicated that the most important mercury source in the bay is from the sediments (Alcoa, draft RI). Water column samples have shown that mercury is present at elevated concentrations only in a small area near the NPL Site shoreline and the mercury seems to quickly become sequestered in the sediments. The mercury undergoes methylation in the sediments and is cycled through the food web.

In an early cooperative effort (prior to NPL listing), Alcoa and the Trustees undertook a study to develop conceptual mercury exposure models based on estuarine food webs. In this study, Evans and Engel (1994) considered "the partitioning, bioconcentration, and bioaccumulation of inorganic mercury and methyl mercury in aquatic ecosystems which could be used to define the connection between mercury contamination in the sediment and elevated mercury levels in Lavaca Bay biota" in the models that were developed. The authors determined that the direct uptake of mercury from the water column was a "trivial" source and sediment was the main uptake route (Evans and Engel 1994). Wiener and Spry (1996) noted that "wild fishes" obtain methyl mercury mostly through the diet.

Evans and Engel (1994) evaluated biota-sediment factors (BSF) between total mercury concentrations in benthic organisms (dry weight) and total mercury concentrations in sediments from the literature. BSF is the ratio of a substance's concentration in tissue versus its concentration in the sediments. Also, BSF values (dry weight) were calculated from paired prey item/sediment mercury contamination data gathered during the remedial investigation B2E Prey Item Study (Alcoa 1998). These data are presented in Table 3. The results for mercury body burdens in the Alcoa report included the shells of mollusks in the sample. In order for an accurate appraisal of BSFs, it would be necessary to correct these results to include only actual live tissue burdens of mercury. If corrections are made to the tissue concentrations to reflect deleting shell mass diluting the sample; the tissue concentrations of mercury should be higher. This would result in higher BSFs for these organisms that would be closer to the median values reported by Evans and Engel (1994). In any case, for all comparable situations, the range of the BSFs calculated from the Alcoa (1998) data is within the range used by Evans and Engel. Generally, the factors all seem to center around a value of 1. This situation is supported by another recent steady state model developed for marine bivalves for metals (Thomann et al. 1995), which found a BSF of 1.0 for mercury.

Taking this information into consideration, it is possible to make some assumptions and use a simplified process to determine concentrations of mercury in sediments that pose potential risk for the accumulation of mercury in fish tissues above injurious levels in a reasonable worst case scenario. Since a large portion of the tissue data available is for subadult and adult red drum, which is a representative species for open water areas, the models developed by Evans and Engel (1994) for this species can be used to determine sediment concentrations resulting in critical tissue concentrations. Assuming that the bioaccumulation of mercury is adequately addressed, this model can be accepted as representing fish muscle tissue concentrations for red drum resulting from sediment sources allowing conclusions to be developed without additional studies and modeling.

Evans and Engel (1994) found that their model generated a muscle tissue methyl mercury concentration of 0.9 μg/g if the sediment had a total mercury concentration of 1.0 μg/g. This results in a BSF of 0.9. Other BSFs calculated for Lavaca Bay were also close to 1 (Table 3). Based on these data, the Trustees chose to use a BSF of 1 for changing critical tissue concentrations into mercury critical sediment concentrations for large, migratory carnivorous finfish. The critical tissue concentrations from Table 2 were used with the BSF to calculate corresponding sediment concentrations (Table 4) for identifying areas in the bay that pose potential injury for large, migratory carnivorous fish receptors.

Injury to non-migratory finfish species may not be accurately estimated using the red drum data outlined in the previous paragraph. BSFs were calculated from the Alcoa (1998) paired organism/sediment data set that included small, non-migratory fish species. Small home range carnivores such as gobies, killifish and sheepshead minnows were determined to have lower BSF values than that calculated for red drum by Evans and Engel. These small carnivores are very habitat selective primarily occupying oyster reef and low marsh habitats. Killifish were selected as a representative species for those small fish occupying marsh habitats and gobies were selected as representative of those occupying oyster reefs. Data from Lavaca Bay for small, non-migratory carnivores resulted in BSFs of 0.75 for killifish and 0.6 for gobies. As a result, sediment concentrations that pose risk of injury to red drum are not the same as those that present risk to the small carnivorous finfish (Table 4).

The Trustees determined that using BSFs from small, non-migratory, carnivorous fish would be most representative of injury associated with estuarine wetland (killifish) and oyster reef (gobies) habitats in Lavaca Bay. This is primarily based on the fact that these habitats are selectively used by these species, which spend their entire life cycle in closely associated areas. This scenario is supported by the results of the ecological Baseline Risk Assessment performed for the NPL Site (Alcoa, draft BLRA). The BLRA found possible risk for early life stages of killifish, gobies and oysters. The large, migratory carnivorous fish (red drum) would be most representative of injury in the open water areas of the bay system, since they commonly spend time in this area, while the small species noted above seldom use the open water habitats.

Using the sediment concentrations noted in Table 4, the areas within Lavaca Bay that represent areas of injury to finfish species via bioaccumulation can be mapped using the sediment mercury concentration and habitat mapping data from the remedial investigation studies.

Table 1. Selected literature concerning mercury effects associated with tissue concentrations.

Citation	Tissue Concentration	Impact/Conclusion
Niimi and Kissoon 1994	10-20 mg/kg whole body 1-5 mg/kg	Lethal body burden for fish adverse chronic effects body burden in aquatic organisms.
McKim et al. 1976	3 mg/kg in muscle	Maximum allowable toxicant concentration in brook trout.
Olson et al. 1975	1.4 – 10.9 mg/kg whole fish	No observable effects for fathead minnows.

Snarski and Olson 1982	1.4 mg/kg whole fish	Maximum allowable toxicant concentration for reproductive impairment and impaired growth in larval fathead minnows.
Wiener and Spry 1996	>5 µg/g whole body	Probable toxic effects in brook trout.
	3 µg/g whole body	No observed effect level in brook trout.
	>10 µg/g whole body	Sublethal or lethal toxic effects in rainbow trout.
	6-20 µg/g muscle	Adverse effects in salmonids.
	5 µg/g muscle	No observed effect level in salmonids. (Due to neurotoxicity, behavioral and reproductive effects occur at much lower tissue concentrations).
Beckvar et al. 1996 early	0.5 – 1.0 ppm whole body	Concern for reproductive or Life stage effects
Friedmann et al. 1996	0.254 –2.37 µg/g whole body	Impaired growth and immune function impaired testicular development in young
Vollestad et al. 1998	0.27 – 3.80 µg/g whole body	Departure from morphological norm in grayling fry
Fjeld et al. 1998	0.27 – 3.80 µg/g whole body	Subadult impaired feeding efficiency and reduced competitive ability in grayling exposed as fry
Matta et al. 1999 (in review);	0.47 – 11.0 µg/g whole body	Mortality in male mummichog (Fundulus heteroclitus) possibly due to increased aggressive behavior
	12.0 µg/g whole body	Reduced egg production by mummichog

Table 2: Potential injury categories associated with fish muscle tissue mercury concentrations (µg/g wet weight).

Potential Injuries	**Muscle Tissue Concentration**
Behavioral and possible reproductive effects (non-migratory species)	0.5 – 1.0
Behavioral, probable reproductive and early life stage effects (non-migratory species)	1.0 – 2.0
Probable chronic and sublethal effects	2.0 -- 3.0
Chronic and sublethal effects	3.0 -- 6.0
Lethal toxic effects	6.0 – 20.0

Table 3: A comparison of mercury biota-sediment factors (BSF) presented in Evans and Engel (1994) and Alcoa (1998).

Organism Type	Evans & Engel BSF (dw) Median	Evans & Engel BSF (dw) Minimum	Evans & Engel BSF (dw) Maximum	Alcoa BSF (dw) Median	Alcoa BSF (dw) Minimum	Alcoa BSF (dw) Maximum
Worms	2.7	0.12	22.2	1.18348	0.40167	3.87397
Clams	1.5	0.28	27.6	0.63326*	0.44147*	1.31291*
Mussels	0.75	0.08	21	0.12029*	0.04884*	0.23029*
Oysters	1.9	1.2	5.7			
Gastropods	2.68	0.05	75	0.34192*	0.21409*	0.79871*
Shrimp	0.78	0.00	8.6	1.50533	0.64978	2.20377
Blue crabs				1.00866	0.31999	1.67574
Crabs (other)	0.95	0.07	40	0.77349	0.23208	2.33665

* Shell is included in molluscan results and calculations. Corrections may be necessary to give actual BSFs for digestible tissue mercury concentrations.

Table 4. Sediment mercury concentrations associated with critical tissue mercury concentrations for large carnivorous, migratory fish and small carnivorous, non-migratory fish.

Tissue Concentration (µg/g)	Sediment Concentration (µg/g) Large Carnivores Red drum (BSF=1.0)	Small Carnivores Killifish (BSF=0.75)	Small Carnivores Gobies (BSF=0.6)
0.5 (injury to non-migratory fish)	-	0.7	0.8
1.0 – 2.0 (injury to non-migratory fish)	-	1.3 – 2.7	1.7 – 3.3
2.0 – 3.0 (injury to all fish)	2.0 – 3.0	2.7 – 4.0	3.3 – 5.0
3.0 – 6.0 (injury to all fish)	3.0 – 6.0	4.0 – 8.0	5.0 – 10.0
6.0 – 20.0 (injury to all fish)	6.0 – 20.0	8.0 – 26.8	10.0 – 33.0

3.0 QUANTIFICATION OF SERVICE LOSSES

To quantify interim service losses, the Trustees determined how the different concentration ranges of mercury identified with critical tissue concentrations would result in different levels of finfish service reductions (Table 2). For each range of tissue concentrations, the Trustees determined a level of severity for the injury, which corresponds to the percent of services reduced. As noted in the earlier discussion, adverse effects increased in severity and the type of effects possible changed with increasing mercury concentrations. Therefore, the higher the tissue, or sediment, concentration is, the higher the percent loss of services that would occur (Tables 4 and 5).

The Trustees determined separate injury values for each habitat type based on the representative species selected and evaluated earlier for critical tissue concentrations and mercury effects. Since data are available for representative species for marsh (killifish), oyster reefs (gobies) and open water areas (red drum), these data were used to evaluate injury levels for these habitat categories. This allowed a more accurate determination of acres of habitat affected since specific mercury data (fish tissue and sediment concentrations) were available from each of these habitats. Thus, the injury levels for estuarine wetland (marsh) and oyster reef habitats were based on the concentrations associated with small, non-migratory carnivorous fish (represented by killifish for marsh and gobies for oyster reefs). The injury levels for open water areas were based on large, migratory carnivorous fish (represented by red drum). Using habitat mapping information and the nature and extent of contamination data from the Remedial Investigation, the Trustees were able to determine the number of affected habitat acres at each of the relevant tissue mercury concentrations via converting the tissue concentration into the corresponding sediment concentration (Tables 4 and 5). Using the data in a Geographic Information System (GIS) allowed the areas of concern to be digitally outlined on a validated base map of the bay, and the acreage of the outlined areas to be accurately calculated. Table 5 presents the different mercury concentrations of concern, the corresponding level of service reduction assigned and the number of affected acres determined by this process for each habitat type.

Table 5. Results from the quantification of service losses for fish injuries and the number of acres of habitat affected in Lavaca Bay by these injuries. Injury was based on an assessment of mercury critical tissue concentrations for potential effects on representative species of small, non-migratory carnivorous fish for marsh (killifish) and oyster reef (gobies) habitats and on large, migratory carnivorous fish (red drum) for open water areas. Mercury concentrations are presented as μg/g.

Mercury in Tissue	Mercury in Sediments	Services Lost	Number of Affected Acres
Marsh (Wetland) Habitat			
<0.5	<0.7	0	0
0.5 – 1.0	0.7 – 1.3	10 %	15.4
1.0 – 2.0	1.3 – 2.7	20 %	3.28
2.0 – 3.0	2.7 – 4.0	30 %	0
>3.0	>4.0	40 %	0
Oyster Reef Habitat			
<0.5	<0.8	0	0
0.5 – 1.0	0.8 – 1.7	10 %	3.13
1.0 – 2.0	1.7 – 3.3	20 %	1.09
2.0 – 3.0	3.3 – 5.0	30 %	0
>3.0	>5.0	40 %	0
Open Water			
<2.0	<2.0	0	0
2.0 – 3.0	2.0 – 3.0	20 %	9.58
>3.0	>3.0	30 %	2.5

4.0 HISTORIC TRENDS IN FINFISH SERVICE LOSSES

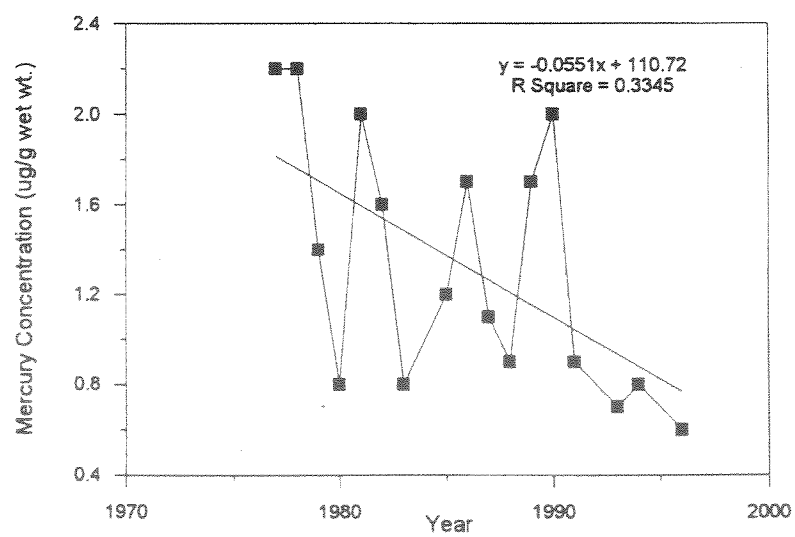
Data from the bay indicate that historically mercury concentrations were higher in fish tissues (Alcoa, draft RI). As noted in the previous quantification of injury discussion, higher tissue concentrations of mercury are associated with greater injury to the fish. This indicates that historically the injury levels for finfish in Lavaca Bay were probably higher than the injuries presently characterized.

For the Trustees to assess the change in historic injuries and determine the related service losses, data sets had to be evaluated for possible trends. Several factors influence whether data are appropriate for trend analyses, including the fact that mercury analytical methods have changed resulting in different detection limits and accuracy of data; that the greater the time gap between samples makes the data more questionable for trend analyses; and that the number of samples influences the ability to determine trends. The Texas Department of Health (TDH) has collected several species of fish for mercury analyses since the early to mid- 1970s. These data were collected for human health determinations relating to the various fish and shellfish consumption advisories and the closure established in the bay. These data provide results obtained with consistent field techniques and from the same analytical laboratory. Although there are some data gaps, this is the most complete data set available for trend analyses. The Trustees decided to use the TDH data to determine how mercury concentrations in fish tissues changed over time and how these changes influenced the resulting service losses for finfish.

In examining the TDH data, it was found that two species (red drum and black drum) had the greatest amount of data for the most years with the highest numbers of samples available for trend analyses. Since these long-lived species have been found to readily bioaccumulate mercury and serve as representative species in the injury determinations, they are good representatives to use in determining trends.

Black drum had the best data set with the fewest number of years lacking samples and no obvious data outliers (Figure 1). Although the data values varied considerably, a linear regression analysis found a significant (P=0.015) negative regression (regression coefficient [slope] = -0.055) with an R square of 0.3345. Figure 1 shows the data points and the regression line indicating that mercury concentrations were higher in the past.

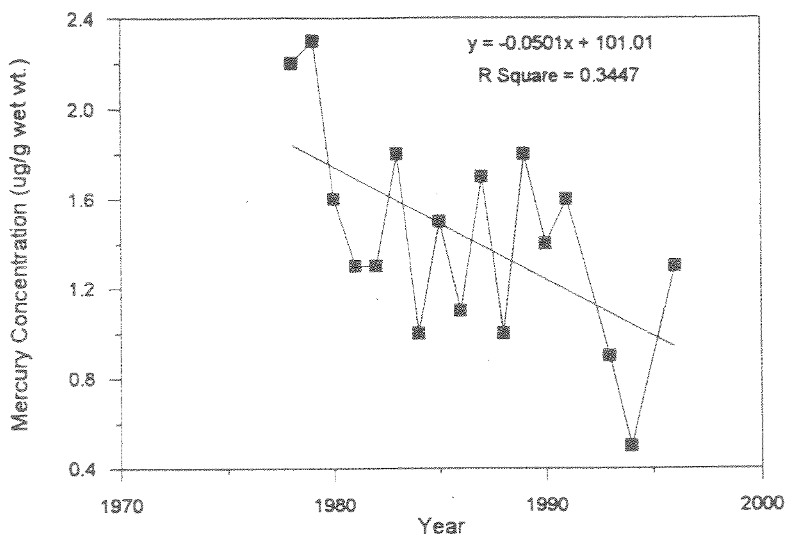
Figure 1. Lavaca Bay black drum historic trend analysis.



Note: Texas Department of Health fish fillet data.

Red drum had the most data points over the years, but had several major time periods without samples and several inconsistent data points that are probably outliers. Data from 1970 and 1971 were much lower in mercury concentrations while 1977 data had much higher concentrations. If values for these outlier years were eliminated, the linear regression analysis results indicate a significant regression (P = 0.0132). The analysis found a negative slope (regression coefficient = -0.0501) with an R square of 0.3447 (Figure 2). These results are very similar to the black drum analysis results.

Figure 2. Lavaca Bay red drum historic trend analysis.



Note: Texas Department of Health fish fillet data.

With similar results from the analyses for these two species, the Trustees decided to use a slope of –0.05 in assessing the historic trend in injuries and service losses for finfish resources. The historic losses are evaluated back to 1981. The regression lines in Figures 1 and 2 illustrate that a slope of –0.05 indicates that in 1981 the mercury concentrations were about twice the more recent concentrations. Using the conservative assumption that injury levels would similarly double, the Trustees will use service losses for 1981of two times those determined for the present. Hence, while service losses of 10%, 20%, and 30% exist for areas associated with present (1999) injuries (Table 5), service losses of 20%, 40%, and 60% will be assigned to these areas for 1981. The Trustees will linearly vary these service losses from the 1981 values to the present 1999 values, thereby following the slope determined in the regression analyses above.

5.0 RESTORATION GOALS

The Trustees have determined that the service losses associated with injury to finfish resources can be restored by projects that sufficiently increase the habitats used by the injured resources in Lavaca Bay. By increasing the amount of habitat in Lavaca Bay that supports the resident fish community, the carrying capacity of the system for these resources will increase allowing the finfish injuries to be offset by the future gains. This is especially true if important habitats for the injured fish resources, such as reproductive sites, nursery habitats, and habitats with protective structures, are targeted for increases. Habitats identified by the Trustees, as preferred for achieving restoration objectives for fish in Lavaca Bay, are estuarine wetlands and oyster reefs. These habitats provide nursery sites, protective cover, food resources and other vital services necessary for healthy estuarine finfish communities. These habitats are important to the finfish species injured in the Lavaca Bay ecosystem, as indicated by the representative species used in this assessment. By providing these habitats finfish species injured by mercury in Lavaca Bay will benefit. The Trustees will use a Habitat Equivalency Analysis (HEA) to determine the amount of these habitats necessary to offset the service losses associated with the finfish resource injuries identified in this document.

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